DEFORMATION OF CRYSTALLIZING MAGMA

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In the foregoing paper Professor Grout raises certain objections to processes that I have advocated as significant in petrogenesis, and to some of these objections I wish to take the opportunity, offered by the editors, of making a brief reply.

With particular reference to the Duluth gabbro, Grout says that "the arguments for circulation are conclusive," but offers no further support for the arguments than that formerly offered. The banding and fluxion structures are conclusive evidence of circulation of a sort, perhaps, but not necessarily of convective circulation. Convection suffers from the disability of requiring the further assumption of rhythmic crystallization, i.e., crystallization which is periodic with respect to the nature of the substance crystallizing. In this manner it is hoped to obtain alternating layers of different composition, but it would seem much more probable that convection would effect a thorough mixing of the successive products. The rhythmical crystallization itself is, moreover, an assumption that has nothing to support it in the whole realm of crystallization phenomena. The Liesegang ring effect is a totally different affair, and any assumption of rhythm in crystallization, such as Grout pictures, should be made only *in extremis*.

On the other hand the down-warping of the tabular mass of crystallizing magma would seem to necessitate the development of fracturing along planes sensibly parallel to the tabular extension of the mass. The crystalline mesh would be subject to an action that is to all intents and purposes thrust-faulting along these planes. This action opens the possibility of the filling of the fault "fissures" with liquid from the interstices of that portion of the adjacent mesh that happens to be weakest and of developing layers

that have approximately the degree of contrast shown between crystals and residual liquid at the time the action takes place. It must be understood, of course, that the crystal mesh is very weak and not capable of sustaining open fissures, but that local crushing of the mesh, formation of "fissures," and their filling with liquid are absolutely synchronous.

Such action, oft repeated as the warping continued, would seem to be thoroughly competent to produce the banded structure; nor does it fall behind in ability to produce fluxion structures. The flow of liquid through the pores of the adjacent mesh would not be particularly directional, but in its action of filling the "fissure" it would spread laterally and crystals would be correspondingly oriented. At first thought one might ask: "What crystals?" but it can scarcely be doubted that the thrusting action pictured would result in tearing a multitude of crystals from their relatively insecure moorings along the walls of the thrust planes and in their distribution by the liquid filling the "fissures."

Both the banding and fluxion seem, then, to be readily accounted for by the warping of the mesh as described, but the full consequences of such action are not yet exhausted. The liquid filling the lenticular openings developed carries, as we have seen, a certain amount of crystals, and the alignment of these marks the fluxion structure, particularly where the lenses are thin. In thicker lenses settling of these already large crystals will immediately take place when they are heavy, and there may develop from their accumulation the most extreme of monomineralic layers. Moreover, the liquid, thus purged of its suspended crystals, begins to crystallize itself under conditions that could scarcely be more favorable for differentiation by crystal settling. The temperature gradient is exceptionally low for a liquid mass just beginning to crystallize. Slow cooling and freedom from convection, the arch enemy of differentiation, are thus assured and the extent to which sorting of crystals is carried as these quiet pools crystallize is not likely to be matched in any ordinary type of intrusion. Not only the normal bands of moderate contrast may be produced by this warping action, therefore, but also bands of the most extreme types as an ultimate consequence.

We may pass on now to a consideration of the squeezing out of liquid at a still later stage of crystallization to form a distinct differentiate such as a granophyre mass. The breakdown of the crystal mesh at this stage would still, I believe, be accomplished by fracturing along areas of contact between two adjacent crystals and subsequent revolving of the crystals into a position permitting closer packing. There is later, too, a further growth of crystals dependent upon the amount of liquid ultimately left in the interstices, and the final result would be a panidiomorphic granular (not granulated) mass showing normal crystallization textures. The production of broken crystals and of granulation belongs to a later stage, when there is a negligible amount of interstitial liquid and shearing forces of a much greater order of magnitude must be brought into action. In all probability such forces do come into play in the production of some anorthosites, but far-reaching results can be produced by filter-press action without any necessity for the development of granulation.

In the case of production of a granophyric body from gabbro magma by expressing of liquid, there is no necessity that the gabbro should show granophyric interstices, for if the cooling is slow enough the granophyric liquid that remains in the interstices may be used up and normally will be used up by reaction with crystals already separated. No one who has examined a section of a gabbro with granophyric interstices can have failed to see the reaction referred to, interrupted before completion. The reaction between relatively large blebs of granophyre produced by immiscibility, while it might be of the same nature, could not possibly be carried to completion.

In conclusion I wish to confess some surprise at Grout's statement that I have made an inaccurate copy of his map of the Duluth gabbro, for the copy was made for me by a competent draftsman. Furthermore, my surprise has been greatly increased on examining my map, going over it minutely with a pair of dividers and finding that it corresponds absolutely, dimension for dimension, with Figure 6 of his paper, "Internal Structures of Igneous Rocks."[1]

[1] *Jour. Geol.*, XXVI (1918), 446.